The VIPER-SEW Project

Building a Robot that Slithers

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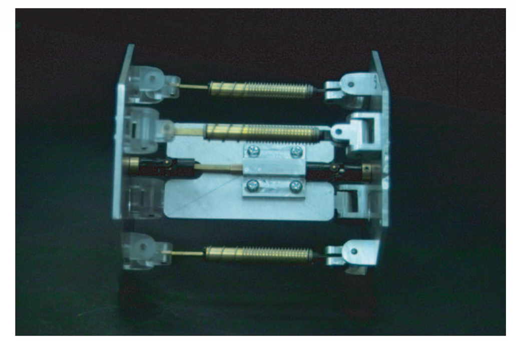
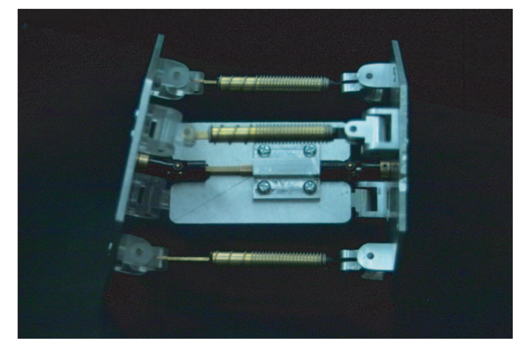
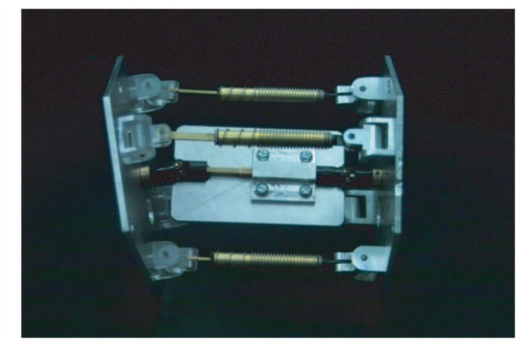
Objectives:

1. To design and build a working segment of a modular Snake-Eel-Worm (SEW) robot for use in a Visualization Integration Platform for Exploration Research (VIPER)
2. To research the feasibility of Shape Memory Alloy (SMA) actuators in robotics applications
3. To experience the Design Process used in Engineering
4. To experience the intricacies of integrating mechanical, electrical, and software elements into a working robot
5. To gain real-world engineering experience







Figures 1-3 (left) Photographs of our prototype segment. Power and control circuitry was not yet installed in these photos.

Methods:

We began the design process by compiling a list of criteria that the completed segment would be required to meet. To give us the full engineering experience, our mentors, Dr. Charles Tolle and Dr. Herschel Smartt, primarily played the role of the "customer," thereby forcing us to determine most of the criteria ourselves.

When the list of criteria was complete, we set about searching for hardware and electrical components that would allow us to meet the various criteria. We were able to find and order some components, such as SMA actuators and the computer that will eventually control the snake. Many other components, however, such as the circuitry that would control the SMAs and the hardware that would comprise the physical body of the segment, were not commercially available, necessitating that we fabricate them ourselves.

To that end, we first prepared many schematics and technical drawings of the parts we would require. Once the drawings were completed, we procured an old CNC mill and, after long hours spent learning how to run it, used it to machine the various mechanical components that were required. Meanwhile, the basic electrical parts necessary for the construction of our control circuitry had been ordered, and upon their arrival we constructed a prototype control board for the snake. Much thought has been devoted to designing the segment's controlling software, but we have not as yet begun to write the actual programs. One key consideration in this regard is the necessity that the individual computers housed in each segment be able to communicate with each other, creating a computer cluster that can not only control the movement of the snake, but handle processor-intensive operations, such as object recognition and visualization.

Results:

By and large, our project was remarkably successful. Our most significant accomplishments are as follows:

The Construction of a Mechanically Functional Segment

In our criteria for the construction of the snake segment, we decided that for a chain of segments to exhibit actual snake-like motion, each segment must have three certain degrees of freedom. Specifically, it must be able to incline its ends relative to each other on both axes, and it must able to increase or decrease its overall length. To achieve these desired degrees of freedom, we anchored a universal joint to the center of an aluminum plate, and connected it to a telescoping tube, which was anchored to the center of a second plate. Four pistons housing SMA wire were mounted between the plates, equal distances from the center (see Figure 4 for segment layout). Thus, by contracting either a single piston or two adjacent pistons by varying amounts, we could tilt the two end plates toward each other along either of two axes of motion. By contracting opposite pistons, we could contract the segment as a whole. To prevent the pistons from being bent by their own contraction as the plates tilted, we designed and constructed u-joint-like mounts for the pistons. Normally, when two adjacent pistons contracted, the telescoping center post would partially collapse, the plate pivoting on the pistons opposite to those contracting. Thus, to increase the angular deflection of the plates, we spring loaded the center post. The force exerted by the spring moved the pivot point closer to the center post, and increased the angle of deflection. This gave us a mechanically functional segment with a maximum angular deflection of just over 30 degrees, as shown in Figure 5.

The Compilation of Data on the Application of SMA Actuators

To use the SMAs as actuators, their characteristics must be well known. Electrical current passing through the SMA wire produces heat and causes it to shorten. Varying the degree to which the wire is heated causes it to contract to different lengths. The goal of testing was to determine the best electrical signal to apply and also an optimum size of wire. Figure 6 shows the electrical test setup. A function generator supplied the square wave electrical signal that turned the MOSFET transistor "on" and "off." When in the "on" state, the MOSFET transistor allows current to flow from the battery to the SMA. The on/off signaling provides a couple of advantages. First, it allows for even heating of the wire. When the current flows, the wire heats up. When the current is turned off, the heat will continue to propagate throughout the wire. Second, by turning the current on for only a percentage of the total time, the drain on the batteries is minimized, extending their operational lifetimes. The percentage of time the current is on is referred to as the "duty cycle."

Wires of different diameters were tested against varying frequencies and duty cycles. The total distance of contraction was recorded as follows:

A duty cycle of approximately 20-40% provides a useful range of linear actuation, regardless of frequency. This range of duty cycles allows for open loop control of the actuators. The test also proved that the diameter of the wire affects the heat conduction and, therefore, its contraction. Generally, as the wire diameter increases the range of full contraction decreases, but this is balanced by an increase in force. This knowledge will help us design the actuators for the overall movement of the snake and its segments.

The Construction of Circuitry to Control SMA Actuators

For actuation to take place there needs to be a way to deliver pulses of current with the desired duty cycle to the SMAs. The duration of each pulse is also referred to as its "width." Controlling the duration is thus known as Pulse Width Modulation (PWM).

A computer controller will initiate the electrical signal by sending a command to a PWM chip to supply a signal with the appropriate duty cycle. The signal will then be delivered to a MOSFET transistor, which acts as a current multiplier, delivering electricity to the SMA wire. The current causes the wire to heat up, contracting in proportion to the degree of heating, as mentioned earlier. The use of a PWM chip saves code in the software and lightens the load on the CPU, but requires more external circuitry, which has both space and power requirements. Because another board is already required for the MOSFET transistors, however, the additional requirements of the PWM chips will be minimal.

The Acquisition of Experience in Engineering and the Design Process

Aside from the physical accomplishments of this project, it has given us, as students, an opportunity to experience engineering vocations first hand. While our mentors led us through the design process, they also deliberately played the role of a customer, rather than a supervisor, allowing us to obtain a more thorough picture of engineering work. This engineering work experience was for us educational, fulfilling, and a valuable foretaste of engineering vocations. It will also look great on a resume. By and large, this project thus met its objectives, not only in terms of research and physical accomplishments, but also in terms of its educational goals.

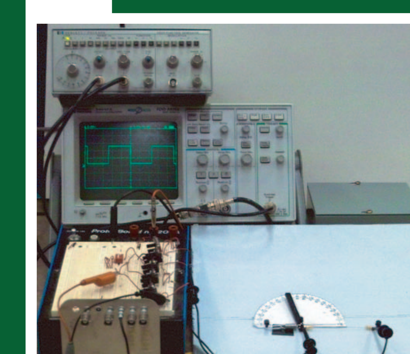
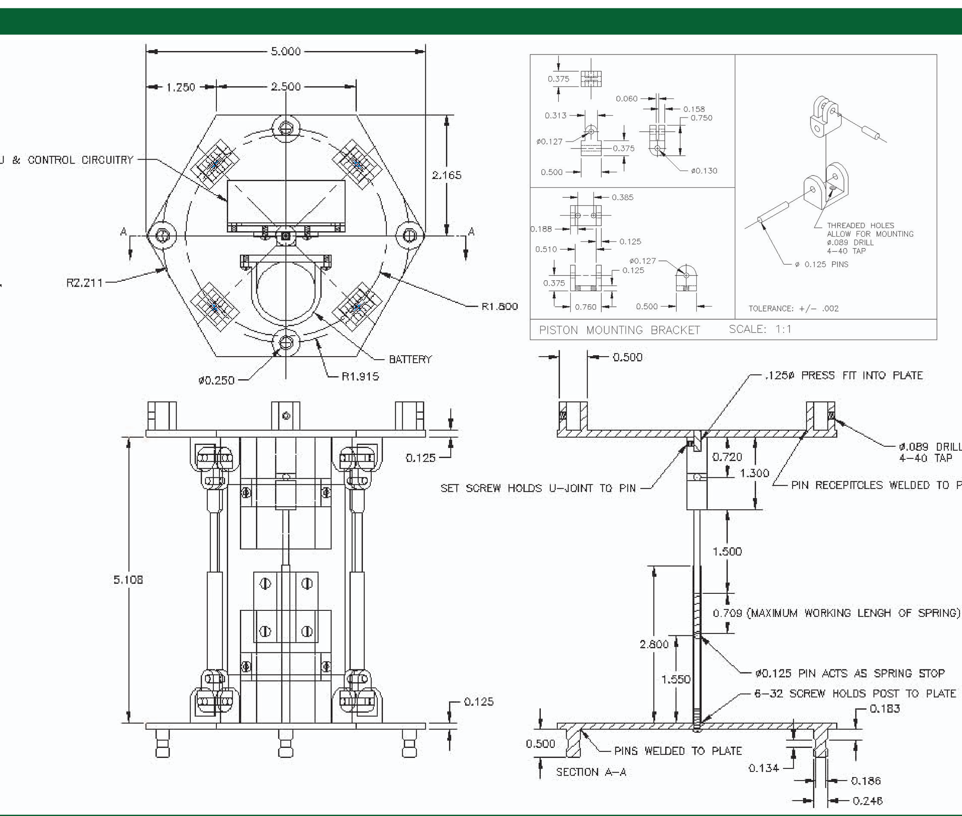


Figure 10 (left) A photograph of our electrical test setup.

Figure 4 (right) The basic layout of the segment, as well as the design of the piston mounts. Dimensions are in Inches.

Figure 5 (below) Diagram of segment angular deflection in one segment and throughout the snake. Dimensions are in Inches



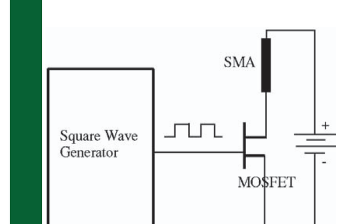
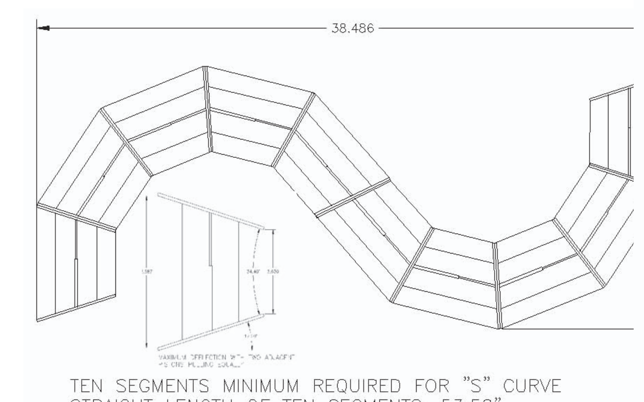


Figure 6 (above) Simplified SMA control circuit.



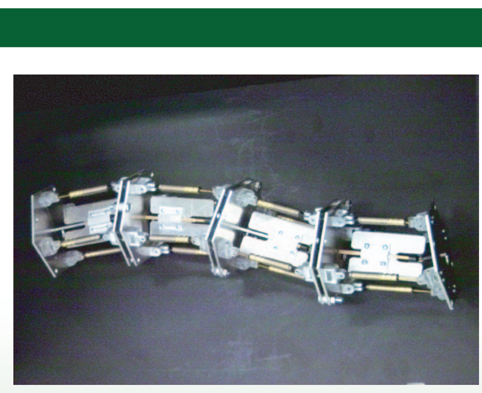
Significance:

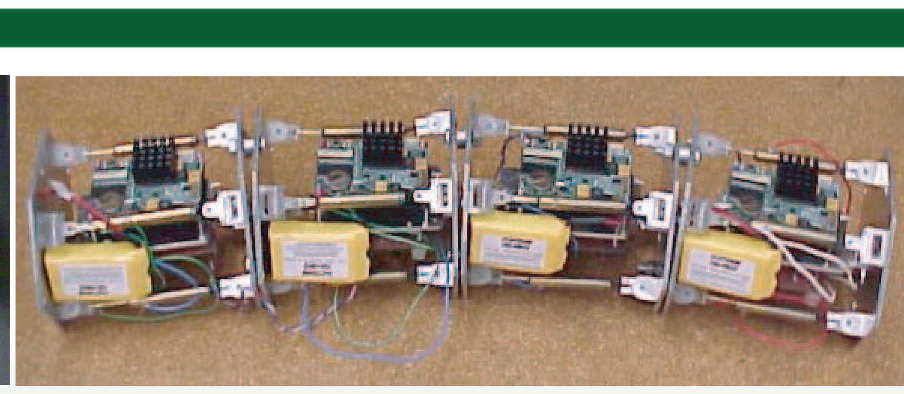
The real significance of our work lies in the remarkable versatility of a slithering motion as a means of propulsion, and the nearly unlimited scalability of an SMA-actuated design. In nature, snakes are capable of navigating some of the most chaotic and unstructured environments known to man. They can slither through building rubble, navigate tight spaces, and move with a great amount of stealth. Additionally, the same slithering motion that propels snakes on land can provide forward thrust in an aquatic environment, provided only that a fin is incorporated into the design. The SEW project is dedicated to taking that versatility of motion and making it available to the world of robotics. Robotic snakes of the future may aid rescue teams by slithering into collapsed buildings to look for surviving victims. They might also perform remote inspection or even construction of underwater structures, such as oil platforms. One could even envision a snake-like robot that could perform stealthy autonomous reconnaissance missions for the military, including scouting for mines both on land and at sea. Such a wide rang of applications can be envisioned for SEW robots because of the great versatility of the slithering motion, and various advantages of SMA actuation and modular construction.

The use of SMA actuators provides several advantages over more traditional means like motors or hydraulics. First, and perhaps foremost, of these advantages is their almost unlimited scalability. Unlike motors or hydraulics, SMAs perform equally well on very large applications, such as an autonomous SEW submarine, or very small ones, even down to nanoscale devices. In addition to this nearly unlimited scalability, SMAs offer the advantage of completely electrical operation. When electrical current is passed through an SMA wire, it heats up and contracts. When the current is cut off, it cools and will return to its original length, provided that a restoring force (such as a spring) is available to stretch it back out. This eliminates the need for fuel, hydraulic fluid, gears, and other substances or components that are prone to wear or leakage. Finally, SMA actuators have an extraordinarily high force-to-weight ratio. That is, an SMA actuator can pull with a great deal of force for its small mass. This makes SMAs very practical in applications where size or mass is restricted, such as the SEW project.

Finally, the modular construction of the snake offers a number of advantages. Perhaps first and foremost, when segments are linked together, their individual computers link to form a computer cluster. Thus, a long snake could process advanced tasks, such as object recognition and autonomous operation, while smaller snakes could be used for less demanding tasks, cutting down on cost. Also, if one segment were to fail, only that segment would need to be replaced, rather than the entire robot, increasing the overall dependability of the design.

Although this summer project is only the first step in the eventual construction of an autonomous robotic SEW, its accomplishments have already been significant. We have demonstrated that SMA actuators can indeed be used to construct a movable snake segment. Furthermore, in the construction of a physical prototype, we have at least created a starting point for further development. Although this is only the first chapter in the VIPER-SEW project, we believe we have already made progress toward the project's ultimate goal of building a useful, intelligent robot that slithers.





Figures 7,8 (above) Photos of our prototype 4-segment snake

Figure 9 (above) A photo of our student development team and our prototype snake. From left to right, Richard Anderson, Dan Hunsaker, Timothy Barnes, and O.J. Schubert.

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